SOUTHERN HEMISPHERE GROUP IV HUMPBACK WHALES: THEIR STATUS FROM RECENT AERIAL SURVEY

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From 1976 to 1994, aerial surveys of Southern Hemisphere 'Group IV' humpback whales, *Megaptera novaeangliae*, were undertaken to provide relative abundance indices of animals migrating northward along the Western Australian coast. These demonstrated a high rate of population increase, at least between 1982 and 1991, of ~10% per year. Surveys were conducted over 10 'good' days in mid-July in an area off Shark Bay, WA, where humpback whales were taken in the last years of Australian whaling, to 1963. The 1994 survey confirmed the increase rate with an estimated population of 4-5,000. The most recent survey, in 1999, planned to obtain an estimate of absolute abundance, was considerably affected by poor weather (only 15 'good' days' flying were possible out of 30 planned over two months). Nevertheless, applying a correction factor for animals missed while submerged to the estimated number of animals sighted gives the 1999 population size within 8,207-13,640. The result is dependent on 'deep diving' time and would be proportionally lower should this dive time be less than the range used (10-15 minutes). We review reported rates of increase and population estimates for this stock in the Antarctic, as well as preliminary Southern Hemisphere population estimates that take account of much larger than officially reported catches in the 1950s-60s. Plans for future surveys are discussed. The population's exploitation history is briefly reviewed. ❐ *Humpback whale, aerial survey, population estimate, recovery, Western Australia.*

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Since 1976 aerial surveys have been conducted off Shark Bay, Western Australia, to investigate possible increase in numbers in the Southern Hemisphere humpback whale, *Megaptera novaeangliae*, Group IV population. That population, summering in the Antarctic between ~80°E-120°E, and wintering off the coast of WA, was severely depleted by whaling twice in the 20th Century, in 1934-1939 and 1949-1963. When Australian humpback whaling ceased in 1963, the population was calculated to have been reduced to 3.5-5% of its pre-1935 state.

Following increasing reports of humpback whale sightings off the WA coast in the early-mid-1970s, surveys of animals during their northward migration were undertaken from Carnarvon (24°52'S, 113°38'E) in an area off Shark Bay. These findings served for comparison with aerial spotter and other data from operations there in the last year of whaling.

This paper reviews the results of aerial surveys from 1976-1999 in the context of estimates of initial population size, recent results from Antarctic surveys and preliminary estimates of current Southern Hemisphere stock sizes.

HISTORY OF EXPLOITATION

Humpback whales were the first Southern Hemisphere whale species to be taken during 'modern' whaling, using steam catcher boats and explosive harpoons. Starting in 1904 at South Georgia, large catches were obtained in the early years, followed by a rapid decline (Mackintosh, 1965). By 1916 some 38,000 animals had been taken in the western South Atlantic (Findlay et al., 2000), with ~8,000 in 1910 and 1911. Over 16,000 were also taken from 1909-1914 on the west coast of South Africa.

'Modern' whaling of humpback whales off Australia began in 1912 (Dakin, 1963). Before that, as elsewhere, 19th Century 'open boat' whalers (using hand harpoons and based on pelagic sailing vessels or from shore), had taken humpback whales but not generally as the preferred prey. Although coastal in habit, at least during their winter migrations, humpback whales were harder to catch than slower moving right whales (*Eubalaena australis*). Their oil was not as sought after as that from right or sperm (*Physeter macrocephalus*) whales, and their relatively short and inflexible baleen was not as valuable as that of right whales. Nevertheless, catches were taken by pelagic whalers on the breeding grounds, for example off Dampier Archipelago, NW Australia, and some during their migration along WA coasts (Bannister, 1986).

'Australian' humpback whales have been generally regarded as belonging to two populations, separated during the breeding season by the Australian continent, and, despite a small amount of mixing, feeding on generally separated Antarctic feeding grounds. Animals breeding off the WA coast belong to the Southern Hemisphere 'Group IV' population, while those off the east coast belong to 'Group V'. These appellations were first used by Mackintosh (1942), the word 'Group' denoting a population occupying a tropical breeding ground and a feeding area (in the Antarctic) to the south. These were based on whale marking results: in the case of Group IV animals, individuals marked while feeding in summer in the Antarctic between 80°-100°E were caught in winter off the WA coast, at ~113°E (Rayner, 1940). The assumption has been that in common with other Southern Hemisphere humpback whales, the Group IV breeding ground is concentrated close to the coast (in this case of WA). In temperate and tropical waters, catches and sightings in both the 19th and 20th Centuries were coastal, suggesting that the animals concentrated near shore and were not evenly distributed across open oceans (Dawbin, 1966). Mackintosh originally recognised five groups, with animals migrating between Antarctic feeding grounds and warmer-water breeding grounds off Chile, in the South Atlantic, off South Africa, off western Australia and off eastern Australia/New Zealand. Their formal longitudinal limits were taken from known baleen whale feeding grounds, including those of humpback whales. The Group IV population was thus designated as occurring between 70°E-130°E. In 1965, Mackintosh amended his five groups to six, to include two in the South Atlantic, one wintering off Brazil, the other off western Africa. More recently, seven major groups have been suggested (International Whaling Commission, 1998a), including one in the central South Pacific, but the distinction between animals wintering off the west and east coasts of Australia remains.

Twentieth Century humpback whaling on the Group IV population off the WA coast occurred in three main phases: i) 1912-1916, 1922-1928, with shore-based catches mainly from Norwegian Bay/Point Cloates, NW Australia (Dakin, 1963; Chittleborough, 1965); ii) 1935-1939, pelagic catches off the W coast (Chittleborough, 1965); and iii) 1949-1963, shore-based catches from Point Cloates (1949-1955) and Carnarvon (1950-1963) on the W coast, and from Albany (1952-1963) on the S coast (Chittleborough, 1965; Bannister, 1964).

The major catches were taken in the pre- and post-WWII periods 1935-1939 and 1949-1963. Chittleborough (1965) records 7,244 animals taken off WA in the former and 12,312 to 1962 in the latter. A further 87 were caught in 1963 (Bannister, 1964).

In addition, between 1928-1938 and from 1948 to at least 1963, there was pelagic whaling on the Group IV population at the other end of the migration, on the Antarctic feeding grounds. Prior to WWII ~6,000 animals were taken, and post-WWII a similar number was officially recorded as caught between 1950-1962 (Chittleborough, 1965). By 1963, the stock decline resulting from catching at both ends of the migration was so severe that whaling had become uneconomical and Australian humpback whaling ceased.

Chittleborough (1965) calculated that the Group IV stock depletion to 1962 could have been from a high of 17,000 animals prior to 1935, from ~10,000 in 1949, and to fewer than 800 animals at the end of 1962. Including the 1963 catch, the decline was calculated as to <600 by the end of that year (Bannister 1964).

Revelations of unreported illegal Southern Hemisphere pelagic catches by Soviet fleets before and after 1963 (Yablokov, 1994) have led to a considerable revision of the catch figures. The overall Group IV catch is now estimated as ~17,040 for 1947-1963, and ~480 for 1964-1967 (Findlay et al., 2000, tables I and II, where 'breeding stock D' is equivalent to Group IV, except that for catches south of 40°S, those for Group IV have been taken as occurring between 60°E-120°E [IWC, 1998a]). The revision of the Group V population (= 'breeding stock E' in Findlay et al., 2000, but between 120°E-170°W, south of 40°S) is even higher. Chittleborough (1965) believed that to explain the very high mortality coefficients he obtained for that population over the short period 1959-1962 there must have been unreported catches in the order of 5,000 in 1961 and 1962. In fact, for the Group V population the true total catch for 1959-1962 is estimated as 15,975 (Findlay et al., 2000), compared with 3,918 reported at the time (Chittleborough, 1965); for the years 1961-1962

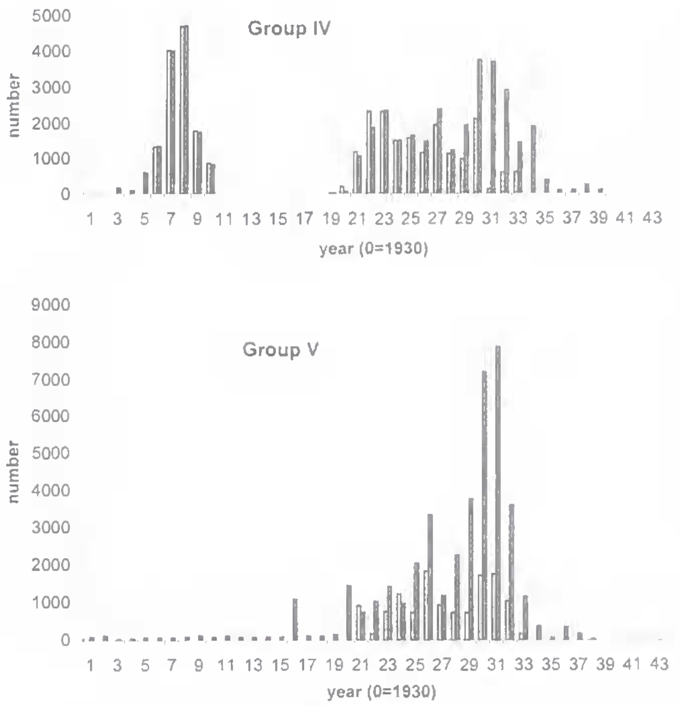

FIG. 1. Comparison of 'official' (light column) and actual (dark column) catches from the Group IV and Group V populations, 1930-72.

it is 3,549 compared with 1,483. For that stock, and for Group IV, considerable illegal catching had been occurring even earlier than Chittleborough supposed. It should be noted however that at least two Group V substocks have been recognised, from their breeding ground distribution, one centred on the Australian east coast, the other on Fiji/Tonga (Dawbin, 1966). Chittleborough's Group V population estimate was based largely on a breeding component on the east Australian coast and a feeding component between 130°E-170°W. A comparison of reported and actual catches for both stocks is given in Fig. 1.

AERIAL SURVEYS

1976-1994 SURVEYS. An indication of the very low humpback whale stock levels in the mid-1960's was given by the results of a survey for sperm whales off the WA coast, flown at monthly intervals from April 1963 to March 1965 (Bannister, 1968). Only ten humpback whale contacts were recorded. The flight path covered an area seawards of the continental shelf, but observations were made from the shoreline off Shark Bay, Geraldton, Perth and Albany, thus covering the humpback whales' north and south migration routes. From then until the early 1970s there were few, if any, reports of sightings along the WA coast, in line with the conclusion of Findlay et al. (2000) that Southern Hemisphere stocks were at their lowest level in about 1968 — perhaps less than 1,000 animals.

In winters of the mid-1970's reports began of humpback whale sightings off WA in former concentration areas such as Shark Bay. Aerial surveys were conducted there annually from 1976-1978 and repeated in 1980, 1982 and approximately every three years thereafter (Bannister, 1985). Surveys were designed to cover the area searched by the whaling operations, particularly outside Shark Bay, where catching had been concentrated in 1963, the last year of whaling there. From 1982 each survey covered the same area, with the same flight path, type of aircraft and, as far as possible, the same pilot and observer. Each took place over ten 'good' flying days in mid-July when the maximum number of animals would be moving northward through the area.

Results to 1988 (Bannister et al., 1991) showed significantly more humpback whale sightings in the area in the 1980's than in 1963. Further surveys, in 1991 and 1994, demonstrated annual increase rates of ~10% (instantaneous rates, obtained from the regression of Log n of the average number seen per flying day each year, of $10.09 \pm 3.0\%$, $10.00 \pm 4.6\%$ respectively; Bannister, 1994, 1995). Using a log-transformation of the number seen on each flying day in each year, 1982-1994, the annual rate was $10.15 \pm 4.6\%$ (Fig. 2). Such high population growth rates, i.e. $\geq 10\%$, are considered to be within the maximum biologically possible (IWC, 1998b) and are feasible if: the average pregnancy rate is 0.5; survival rates are high (at least 0.96); and the age at first parturition is relatively low, i.e. at a maximum of 8 years (Brandao et al., 2000).

By comparison with the estimated population of 568 at the end of 1963 (Bannister, 1964), the size in 1994 was estimated at 4-5,000 (Bannister, 1995).

The 1994 survey results indicated that to detect

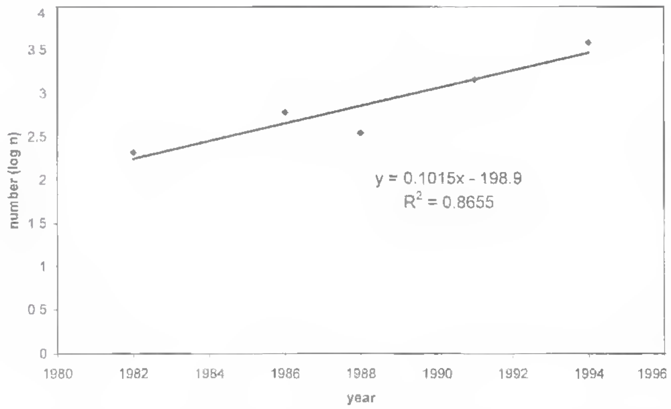

FIG. 2. Aerial survey, outside Shark Bay, 1982-94: regression of sighting rates per flying day (log-transformed, i.e. Log *n*) per year.

a significant difference in population size in future years, at an annual rate of 10%, an interval of three years would be required between surveys (N. Caputi, in Bannister, 1995). Given funding constraints, that survey was carried out in 1999.

1999 SURVEY. Previous surveys, originating in 1976 and modified in 1982, were designed to provide a relative index of abundance over a relatively short period (ten 'good' flying days) in mid-July, during the animals' northward migration. That period was chosen on consideration of expected weather conditions and for comparison with available commercial whaling spotter data, and when most (70%) humpback whales would be moving northwards.

By contrast, the 1999 survey (Bannister & Burton, 2000) was designed to provide an absolute abundance estimate of northward-moving animals, in the same area, but over a longer (~2-month) period than earlier surveys. It used a Partenavia P68B high-wing, twin-engine aircraft (Tropicair Services Pty Ltd) flying at 120 knots and 1500 feet, with two observers, one on either side of the aircraft, seated behind the pilot. Bubble observation windows were fitted to maximise the area swept, particularly to cover the area immediately below the aircraft. A GPS and on-board computer system were available. To measure angles to sightings a clinometer (industry standard Suunto PM-5/360PC) was used for declination, and an angleboard for horizontal angles.

Difficulties with the availability and fitting of the bubble windows and associated airworthiness led to the first two flights taking place without them.

To allow for comparability with earlier results, the same transect grid was flown as in all surveys since 1982, i.e. approximately 80 × 30 nautical miles immediately W of Bernier, Dorre and Dirk Hartog Islands on the western boundary of Shark Bay, between 112°30'-113°10'E and 24°46'-26°09'S (Fig. 3). The N-S distance between gridlines varied between 7-8nm.

To examine the extent of coverage of the humpback whale migration path, transects were extended seawards of the area on two occasions, out to the operational limits of the aircraft (to 112°14.1'E), 50nm W of the northern tip of Bernier I., i.e. 20nm W of the normal seaward limit of the survey at that latitude.

To examine the distribution of humpback whales within Shark Bay, which earlier surveys suggested was a 'resting area' for migrating individuals, flights were conducted in an area ~70 × 30nm between 113°04'-113°35'E and 24°58'-25°32'S, within the bay. All analyses in this paper, however, refer to animals in the area 'outside the bay', where they are assumed to be actively migrating.

Based on a review of migration patterns off western and eastern Australia (Chittleborough, 1965; Bryden et al., 1996; Dawbin 1997) the two month period between 15 June and 15 August was chosen for the survey, during which the majority of northward-migrating humpback whales could be expected to traverse the area. For logistical reasons (availability of observers and aircraft) the period was later amended to 21 June-20 August. Thirty flights (one every second day) were proposed, but it was decided to allow for possible comparison with earlier survey data (i.e. to 1994), by including a period of flights on ten consecutive days over 9-18 July (the 'comparable ten-day period'). On that basis, taking account of the probable changing density of whales over the two months, a variable sampling regime was planned. This required sampling every two days towards the beginning and end of the two months (when numbers could be expected to be relatively low) and — apart from the mid-July 'comparable ten-day period' — every three days towards the middle (when numbers should be higher), while still providing 30 flying days overall.

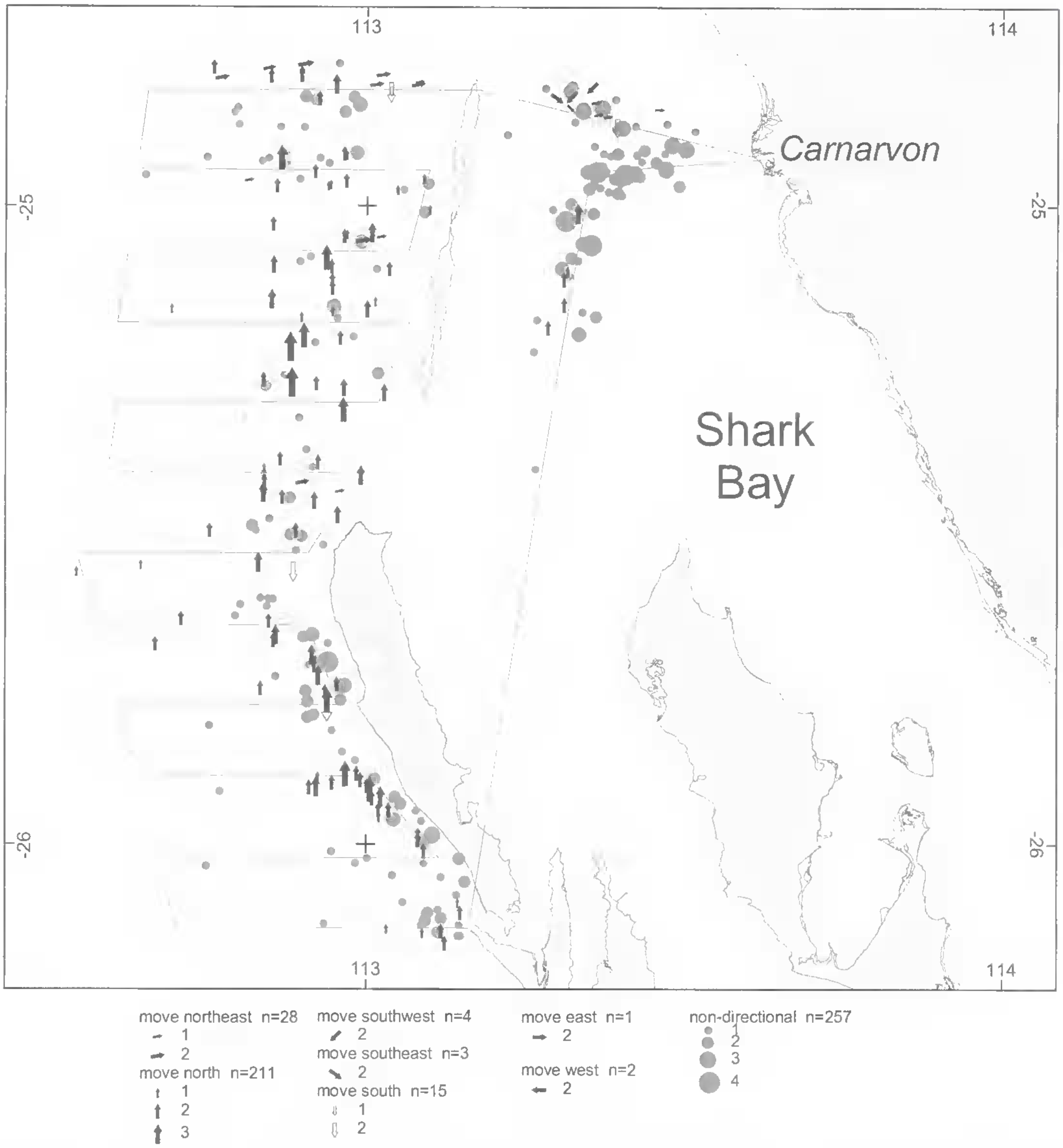

FIG. 3. Aerial Survey, outside Shark Bay, 1999: flight path, sighting positions, numbers and directions of humpback whale movement for the six completed flights within the 'comparable ten-day period', 9-18 July.

RESULTS

FIELDWORK. The planned start date (21 June 1999) was delayed to 24 June, through observer availability and for fitting of bubble windows. The finishing date (20 August) was brought forward to 19 August, again because of observer availability.

Planned coverage of 30 flying days was not achieved because of poor weather conditions — the proportion of 'good' flying days, particularly consecutive ones, was low. Survey days were restricted to those with wind speeds of <15 knots. Only 18 flights could be attempted in those conditions, and of those, 15 were completed, the remaining 3 being terminated early because of deteriorating weather. For the first of the 15 completed days the bubble windows were not available. For the 'comparable ten-day period',

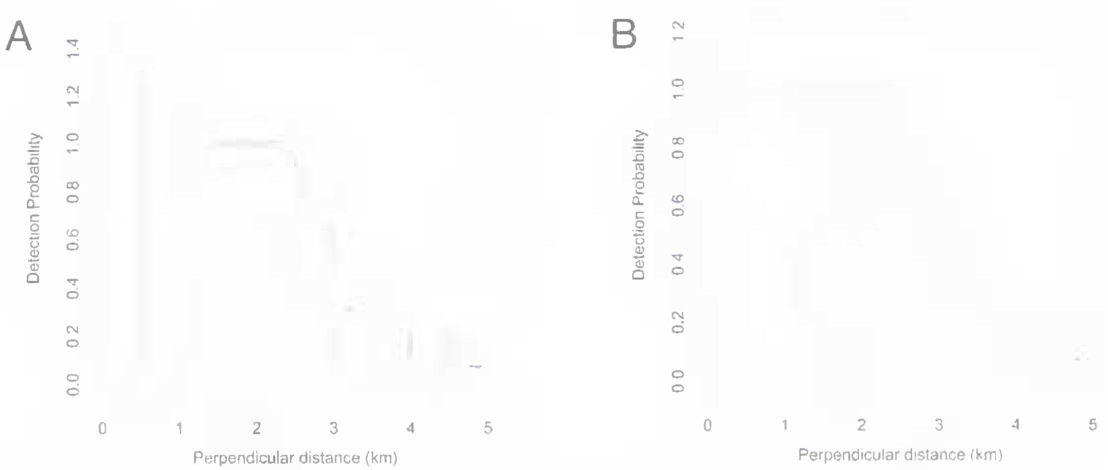

FIG. 4. Aerial survey, outside Shark Bay, 1999: estimation of strip-width. Fitted detection function for chosen (Hazard Rate) model: A, based on exact perpendicular distances; B, based on selected cut-points.

9-18 July, only six complete flights were possible due to bad weather. The extended legs seawards of the main search area were flown as planned, on two occasions, 4 and 27 July.

An example of the results obtained is given in Fig. 3, which shows the flight path and distribution of sightings for the combined 'outside the bay' data for the six completed flights within the 'comparable ten-day period', 9-18 July.

DATA ANALYSIS. *Population Size*. Data from the 14 'good' days flown (excluding the one without bubble windows) were analysed by combining standard aerial line transect methodology with a migration count approach (Bannister & Hedley, 2000). Effective strip width was estimated by pooling data from all flights using DISTANCE software (Laake et al., 1995), which also gave an estimate of mean pod size. The number of pods passing through the surveyed area was then estimated from the daily counts using a FORTRAN program, GWNORM (Buckland, 1992), which fits a density function based on a key function (usually a Normal distribution) and Hermite polynomial adjustment terms, by maximum likelihood methods. Outputs from the line transect analysis and the migration modelling were combined to obtain an estimate of the number of individual whales passing through the survey area during the migration period.

Estimated strip half-width was 3.34km, from a hazard rate model chosen as the 'best' model from four fitted, using Akaike's Information Criterion (Akaike, 1973). Difficulty was experienced initially through significant lack-of-fit for small distances (Fig. 4A) for the candidate model chosen. Clearly the observers, even with bubble windows fitted, either could not see directly beneath the aircraft, or found it preferable to scan out to the horizon and focus on areas further away from the trackline. As a result, for the analysis the data were grouped (Fig. 4B). Estimated mean pod size was 1.87 (95% CI 1.7894, 1.9588); because there was evidence that recorded pod size decreased with perpendicular distance from the transect line, the estimate was obtained from a regression of log (pod size) against perpendicular distance.

In fitting migration models to the daily pod counts, it was assumed that the rate of passage of the whales through the survey area was such that no whale seen on one day would be available for detection on the subsequent day. With the northern and southern boundaries ~90nm apart, an animal would have to travel at an average speed of less than 3.78 knots for the assumption not to hold. Four alternative scenarios were considered (Fig. 5A-D) to allow for analyses of two sets of data (from E-W legs only; from all transects, i.e. including N-S legs) in two different migration periods (80 days, 11 June-1 Sept.; 100 days, 1 June-8 Sept.). The migration periods were based on Group V Australian coastal surveys where there has been some variation in length of the observed northward migration (75-85 days, Paterson et al., 2001; up to 110 days, Bryden et al., 1996). While adding the N-S transects increases the data available for analysis, the use of E-W legs only is preferred, because the analysis relies on the random placement of transects with respect to the whales' distribution.

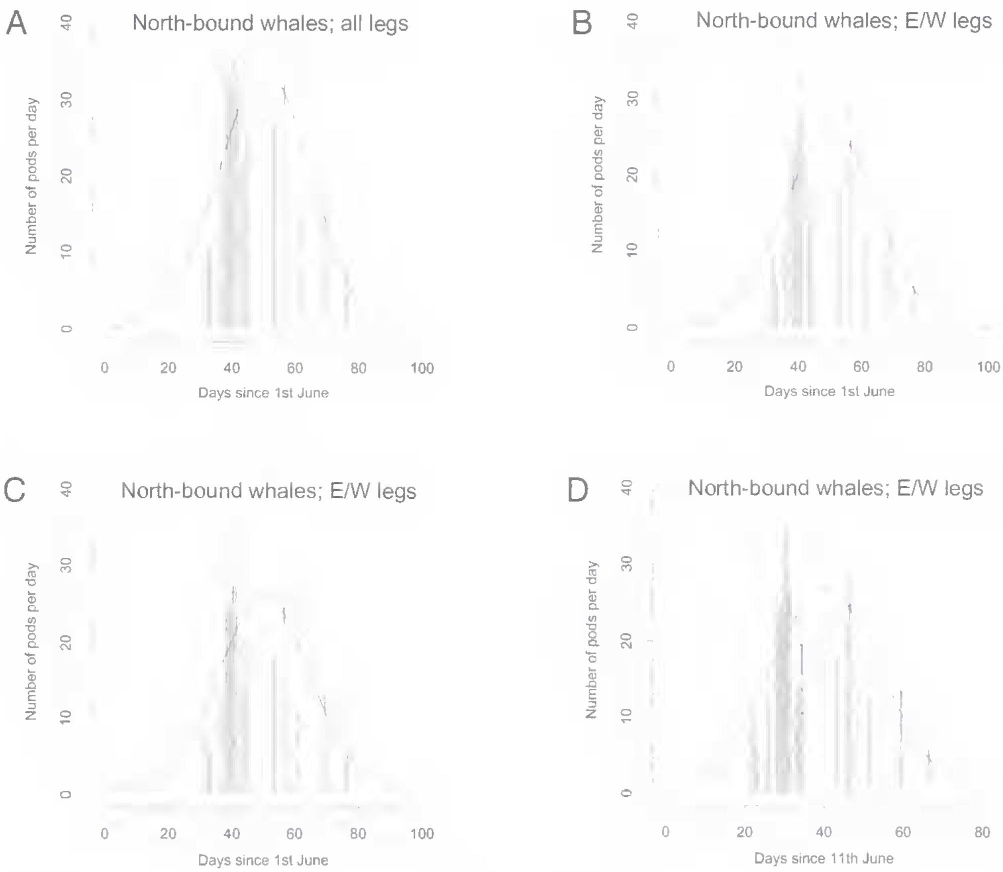

FIG. 5. Aerial survey, outside Shark Bay, 1999: A-D, pods sighted on 'completed' days, together with fitted curves, for combinations of transects (legs) and migration periods.

The E-W transects, being perpendicular to the marked density gradient (with higher densities near the coast and being latitudinally systematically spaced throughout the area [Fig. 3]), provide representative coverage; that is not the case for the N-S transects, use of which gives a biased estimation. Results for the four scenarios (Table 1) give point estimates ranging from 3,249 to 3,441 with 95% CI, with a lower bound of 2,706 and upper bound of 4,294.

Two major factors influenced the 1999 estimate, one operational, the other analytical:
i) Data quality. Given the 60 days allocated for the survey and the planned coverage of 30 flights, the number of completed flights (14) is small for fitting to a migration model, particularly given the unevenness of the coverage. Also, the expected peak of the migration (around mid-July) was inadequately sampled. In addition, the weather early in the period of completed flights, judged by wind speed, was generally worse than later. Modal wind speed for the first three completed flights (3, 4, 7 July) was ~12 knots (range 10-16 knots) compared with 8 knots (range 0-12 knots) thereafter; thus it is likely that there was some undercounting in the earlier part.
ii) Estimate of g(0). The probability of detecting animals on the trackline, g(0), was not taken into account in earlier surveys where relative abundance indices were the objective. For the

TABLE 1. Aerial survey estimates of population size, 'outside' Shark Bay, Western Australia, 1999, northbound animals only. *Number of animals; ** 95% C.I.

Legs	80 day period (11 June-1 Sept)		100 day perio (1 June-8 Sept)	
	Estimate*	Range**	Estimate*	Range**
E-W	3,365	2,706-4,185	3,441	2,757-4,294
All	3,249	2,720-3,881	3,434	2,864-4,117

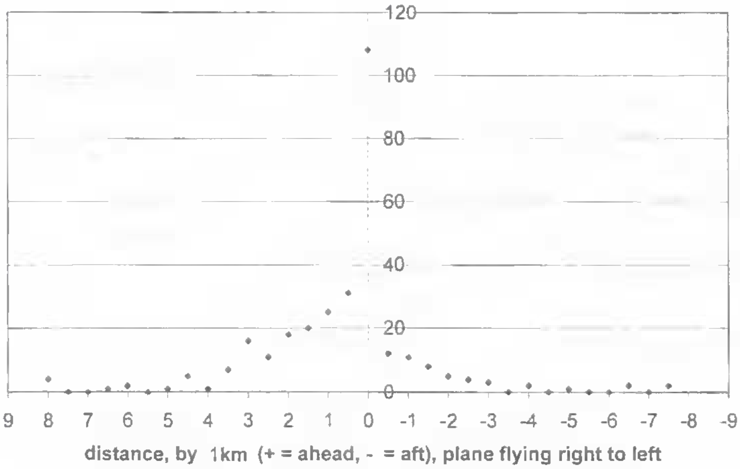

FIG. 6. Aerial survey, outside Shark Bay, 1999: distribution of sighting distances ahead, abeam and aft of the observers, over the six 'good' days, 9-18 July.

1999 survey, where the intention was to obtain an absolute estimate, and given that whales generally spend a considerably longer time under water than at the surface, a knowledge of g(0) is essential. Barlow et al. (1988) derived a correction factor for the probability of missing submerged animals during aerial surveys of eastern Pacific harbour porpoises as:

Pr(being visible) = $(s+t)/(s+d)$

where s = average time an animal stays at the surface, d = average time spent below the surface (i.e. 'deep-diving'), and t = window of time during which an animal is within the visual range of an observer.

Applying the above for humpback whales, values for s, t and d can be estimated with varying degrees of precision. Migrating humpback whales off the WA coast are reported to blow several times at the surface over a period of ~2-5 minutes and then dive for ~10-15 minutes (C. Jenner, C. Burton, pers. comm.). Those observations correspond with the 'longer, presumably deeper, dives of 8 to 15 minutes ... [surfacing] between dives for about 4 minutes, blowing regularly' reported for humpback whales by Winn & Reichley (1985). Information from the Australian east coast, however, suggests that diving intervals may be shorter, with deeper dives ranging from as little as 2 or 3 minutes to 5 or 10 minutes (M. Bryden, R. Paterson, pers. comm.), with larger groups of animals, i.e. 3 or more, diving more frequently than single animals or pairs (M. Brown, pers. comm.). We have taken s for west coast animals as ~2-5mins and d as ~10-15mins, bearing in mind that d, at least, may be overestimated.

To obtain t, a subset of observations of declination and horizontal angles, comprising those obtained during the west coast 1999 survey 'comparable ten-day period', 9-18 July, has been used to provide information on the distance from the aircraft at which sightings were made. In this case the distance calculated was parallel to the cruise track, and not perpendicular to it as in the calculation of strip-width above. The results (Fig. 6) show that a high proportion of sightings was made directly abeam; that may be less a function of the distance at which the animals occurred than the time taken to make the measurements. From the results as presented, a maximum value for the sighting 'window' can be estimated at ~8km, comprising animals seen ahead (generally up to 5km), abeam and aft (up to 3km).

However, estimation of g(0) by this method requires the assumption of a rectangular 'availability window' in which a whale pod at a given perpendicular distance is equally likely to surface at any distance along the length of the window, i.e. parallel to the transect line. Although sightings were clearly peaked abeam (thus violating the assumption), that seems likely to have been caused by the way the measurements were obtained, as noted above. Smoothing the data by eye to obtain a more appropriate idea of the likely rectangular sighting window suggests its length might be less than 8km, i.e. forward to 3.5km and back only to 1km, giving a 'window' of 4.5km, which can be taken as a minimum estimate. At 120 knots, 8km would be covered in 2.2 minutes, and 4.5km in 1.2 minutes.

Minimum and maximum values for the three variables are then: s = 2, 5; d = 10, 15 (although the true minimum value may be <10); t = 1.2, 2.2.

The longer the time the whale spends at the surface (s), and the shorter the time spent deep-diving (d), the greater the probability of seeing all animals present; the converse is true for the sighting 'window' (t). The most conservative population estimate is that derived by using the highest probability of detecting animals, while the least conservative is that derived using the corresponding lowest probability. However, these probabilities are unknown, and the data are insufficient to estimate them accurately. Given the uncertainties, the likely 'highest' probability (Pr max) has been estimated using $s = 5$, $d = 10$, $t = 1.2$, and the likely 'lowest' probability (Pr min) with $s = 2$, $d = 15$, $t = 2.2$, noting that other values for these parameters are also potentially feasible (e.g. $d < 10$) and may thus extend the range of detection probabilities.

Then Pr max = (5 + 1.2)/(5 + 10) i.e. 0.41; while Pr min = (2 + 2.2)/(2 + 15) i.e. 0.25.

Applying those factors to the more conservative of estimates in Table 1 (that for the 80 day period and E-W legs only, 3,365) gives a minimum adjusted population estimate of 8,207 and a maximum of 13,460. If d were indeed <10, the minimum estimate could be lower, but it is not possible to say by how much. If, for example, d were as low as 5, the probability of detecting the animals on the trackline would be increased to 0.62, and the adjusted population size would be reduced to 5,427.

It seems appropriate to conclude that the population passing through the survey area in 1999 would have numbered more than the most conservative estimate unadjusted for g(0), i.e. 3,365. With 'deep diving time', d, of 10-15 minutes, the 1999 population size lies within the range 8,207-13,640. However, should d indeed be closer to 5 minutes than 10, the lower bound could be 5,427.

From the most recent survey results (Paterson et al., 2001) of animals migrating along the Australian east coast past Stradbroke Island, Queensland, Group V population size (at least as it refers to animals migrating along the Australian east coast) in 1999 was 3,600 ± 440 (95% CI). Another east coast survey, in 1999, did not yield conclusive results (M. Brown, pers. comm.): poor weather led to a lack of observations at the migration peak. But based on a successful survey in 1996, and at an increase rate of 12.3% (Bryden et al., 1996), that part of the Group V population size in 2000 would be ~4,600. The Group IV (Antarctic Area IV and Australian west coast) population has generally been considered larger than that of the Group V (Antarctic Area V and Australian east coast) population, by some 20-70% (Chittleborough, 1965). On that basis the two recent Group V results would imply a 1999 Group IV population size of 4,300-7,800, i.e. somewhat less than the range calculated with a diving time of 10-15 minutes.

In all the above it has been assumed that an estimate of the number of animals passing 'outside' Shark Bay for the full extent of the northward migration will be a true estimate of Group IV population size as a whole, i.e. that the great majority of the population migrates past Shark Bay each year. That does not take into account the possibility of sex-biased migration (Brown et al., 1995), nor that in any one year some animals may not migrate as far north up the WA coast as Shark Bay. Given those possibilities, any figure obtained for Group IV population size from aerial surveys off Shark Bay is likely to be a minimum estimate.

RECENT ANTARCTIC ESTIMATES

Independent estimates of population size and increase rate for the Group IV population have been derived from sightings obtained during the Japanese Research Programme in the Antarctic (JARPA) in Area IV, which includes the Group IV feeding grounds (Matsuoka et al., 2000). Sightings south of 60°S from two sources (dedicated sightings vessels and sighting and sampling vessels) give estimates of abundance in the 1999/2000 Antarctic summer of 12,664 (coefficient of variation = 0.28) and 11,138 (CV = 0.29) respectively. Density estimates from six seasons' data, between 1989/1990 and 1999/2000, give an instantaneous increase rate of 12.41% (Matsuoka et al.: fig. 5), equivalent to an annual rate of 13.2%. It should be noted, however, that there is a small amount of intermingling between animals from each population on the feeding grounds (Chittleborough, 1965; Dawbin 1966), particularly in Area IV to the east of 115°E, so estimates of abundance based on Area IV as a whole (i.e. to 130°E) are likely to be overestimates of the Group IV population.

The Area IV-based population sizes quoted above lie in the upper part of the range calculated for the 1999 Australian west coast survey. In addition to the intermingling already noted, differential migration, where not all animals migrate northward each year, would result in a higher estimate in the Antarctic. Similarly, the increase rate, although within the 95% confidence interval for the Australian west coast estimate (10.15 ± 4.6%), is higher than the point estimate, and of the order of that recorded recently for animals on the east coast (e.g. Paterson et al., 2001).

RECENT SOUTHERN HEMISPHERE POPULATION ESTIMATES

Preliminary assessments of Southern Hemisphere population size based on Antarctic catches, adjusted to account for the previously unreported illegal Soviet take and using reported increase rates and target stock sizes (Findlay et al., 2000), place the 1999 Group IV population at 7,686 using the 1977-1991 Australian west coast annual increase rate of 10.9% and 1991 stock size of 3,300 (from Bannister, 1994). The major effect of the greatly increased catches is to increase the estimates of initial population size. Various combinations of catches apportioned between the relevant stocks are used; the above uses the 'Base Case' scenario, with a 'naïve' catch apportionment and no overlap between Groups. For Group IV, rather than the earlier estimate of 12-17,000 (Chittleborough, 1965), initial population size is preliminarily estimated as ~21,000. While the Group IV stock has so far shown encouraging recovery, it is still estimated as some 4,900 (39%) below Maximum Sustainable Yield Level (MSYL, 60% of initial stock size) of 12,600. By contrast, the Group V stock is still considerably depleted, despite a high recent increase rate of 12.3%; the preliminary estimate of 1999 stock size of 4,615 is ~11,500 (71%) below MSYL. The lowest point for either population would have been reached in 1968, with an estimated 268 animals in the Group IV population and 104 in Group V.

FUTURE AERIAL SURVEYS

Given the disappointing 1999 aerial survey results off Shark Bay, particularly the small number of days' coverage, plans are in hand to undertake another survey in the same area and over the same period as soon as possible. The following considerations will be taken into account.

i) The survey should again have the objective of providing an estimate of absolute abundance of northward migrating animals in the Group IV population.

ii) The former 'box-search' flight path should be replaced by a 'saw-tooth' (zig-zag) format, to provide unbiased, representative, coverage. Legs should extend seawards from the western limit of the bay, i.e. the western shores shore of Bernier, Dorre and Dirk Hartog Is, to allow for migrating animals apparently concentrated close to the coast there (Fig. 3).

iii) To 'ground-truth' the aerial survey sightings, and to provide estimates of swimming speed and diving interval, a program of land-based sightings should be undertaken over at least ten 'good' days from an appropriate location, possibly the southern part of Dirk Hartog Island. This should occur towards the middle of the survey period, i.e. at the expected peak of the migration. It is important that flying and land-based observations occur on the same days.

Timing of surveys beyond the next one should be determined from its results, using a power analysis similar to that undertaken previously (Caputi, in Bannister, 1995) on which the survey planned for three years after 1994 was based. At an annual increase rate of ~10%, 60% initial population level (i.e. 12,600) might be reached very soon: from a 1999 level of 8,000, for example, it would be reached by the year 2002, and from 5,000 by the year 2006. It is clearly important that the next survey should be undertaken as soon as possible.

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